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Modelling the thermal emission from airless planetary surfaces and sub-surfaces

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Abstract

Both the Cassini (NASA/ESA/ASI) and Rosetta (ESA) spacecrafts have onboard a radiometer operating at relatively large wavelengths, respectively in the microwave and sub-millimetric domains. At such wavelengths, these instruments sense the thermal emission not only from the surface but also from a section of the sub-surface of the targeted bodies. As a consequence, the interpretation of radiometric data collected over the airless icy satellites of Saturn by Cassini and over the comet 67P/Churyumov –Gerasimenko by the Rosetta orbiter requires a good knowledge of the temperature profile below the surface, down to several meters. In this paper we describe the thermal model we developed in order to interpret Cassini current and Rosetta future radiometric measurements.

1. Thermal emission from airless planetary bodies

Thermal emission from airless planetary bodies hold important clues on the thermo-physical and compositional characteristics of their surfaces. At short wavelengths, in the mid-infrared domain, thermal emission arises from the first layers of the regolith (a few microns). In contrast, radiometric measurements obtained at larger wavelengths can probe deeper below the surface as the material becomes more "transparent". At such wavelengths thermal emission probes several tens of cm up to a few meters below the surface, depending on the absorbing properties of the body's regolith. The radiometric data obtained by spacecraft can be used to constrain the electrical and thermal properties of surface bodies, thus providing clues on their physical state (roughness, porosity) and composition (dielectric constant). This will help identifying the geological endogenic or exogenic processes that have affected these bodies.

2. Thermal modelling

The physical temperature structure of any airless body results from a balance between solar insolation, heat transport within the subsurface and reradiation outward. We have developed a 1-D thermal model able to compute the temperature distribution as a function depth, for any time and location of a given small body or satellite. This model takes into account local variations of the insolation on both diurnal and seasonal timescales. It computes the vertical thermal profile of the surface assuming thermal conduction (depending on thermal inertia, heat capacity, volume density), and will soon include potential vertical gradient of thermal parameters (i.e. in the case of a vertical gradient of density or thermal inertia), surface roughness, and multiple sources of heating (in the case of binaries small bodies or icy satellites heated by the Sun and the parent planet). Integrating the resulting thermal profile over some depth that depends on the electrical properties of the surface material at the operating wavelength then gives access to the effective temperature (or radiometric blackbody temperature) to which the radiometer on board is sensitive.

3. Radiometric spacecraft data

This new thermal model could be used to interpret Cassini radar/radiometer data recorded over some of Saturn's icy satellites and Miro/Rosetta future measurements of the thermal emission of the comet 67P/Churyumov –Gerasimenko.

3.1 Cassini radar/radiometer

For the last 7 years, the Cassini probe has been exploring the Saturnian system. While the Radar on board the spacecraft was primarily designed to observe the surface of Titan, it is occasionally used to examine other Saturn's moons from long ranges and, less frequently, during close flybys. In particular, the Cassini radar/radiometer had the opportunity to observe Iapetus (September 2007), Rhea (March 2010) and, more recently, of the south hemisphere of Enceladus, near the active geysers of the satellite (November 2011) during close-targeted flyby..

The Cassini Radar instrument is a multimode microwave multiple-beam sensor operating at 13.78 GHz (2.2-cm wavelength). It also includes a radiometer (same wavelength) that is able to observe simultaneously with, or separately from, the active measurements. Each Cassini Radar observation consists in collecting unique sets of radar (active) and radiometry (passive) data. In the active mode, the instrument accesses the surface reflectivity through the backscattering cross-section. In the passive mode, it measures the surface microwave thermal emission, which varies with the emissivity (=1-reflectivity) and the temperature distribution in the subsurface (through the effective temperature, see section 2). Combined with the concurrent active data and compared to a thermal model, the radiometry data can be used to constrain the electrical and thermal properties of Saturn's airless icy satellite's surfaces.

3.2 MIRO/Rosetta data

Within 2 years, the MIRO/Rosetta instrument (Microwave Instrument for the *Rosetta* Orbiter) which capabilities have been demonstrated during the Rosetta flybys of asteroids Steins and Lutetia will observe the thermal emission from the comet 67P/Churyumov–Gerasimenko. This instrument includes two mm/submm channels (1.6 and 0.5 mm), probing different depths into the comet nucleus surface, thereby sounding its thermo physical properties and physical state. Our thermal model will allow us to reproduce MIRO measurements by including the 3-D shape model of the comet, which will be used to compute local shadows due to the specific topography.